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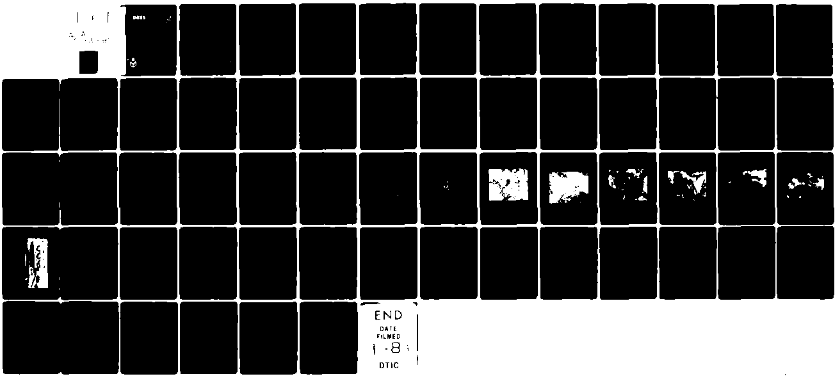

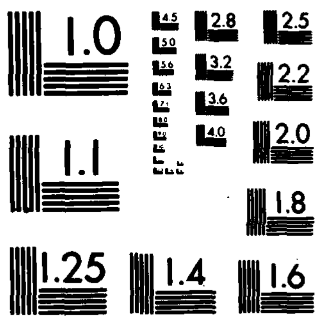

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EVALUATION OF A PROTOTYPE MAGNETIC SURFACE CLEARANCE VEHICLE (U)

by

J.E. McFee
Y. Das
R.H. Chesney

PROJECT NO. 27B52

September 1980

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The authors would particularly like to thank Capt. Dave Stevenson of CFB Wainwright for his prolonged efforts in coordinating this trial. His energy and enthusiasm smoothed over the rough spots and allowed the trial to be carried out very efficiently. We thank the Camp Wainwright Commander, Major Gentles, for his keen support and positive attitude toward the success of the vehicle. Mr. Charles Rose of DCMEM and Sgt. D.E. Jones of LETE deserve much credit for the design and construction of the system which performed far better than expected. Furthermore, their suggestions as well as those of Capt. Al Carruthers of DMEO aided greatly in modifications that were made to the trial on site.

Finally, we must acknowledge the excellent photographs taken by Mr. Colin McIvor, H/Photo at DRES.

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EVALUATION OF A PROTOTYPE MAGNETIC SURFACE CLEARANCE VEHICLE (U)

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Abstract

This paper describes trials carried out at CFB Wainwright to determine the feasibility of a prototype magnetic sweeper vehicle for military range surface clearance of unexploded ordnance and shrapnel. The effects on pick-up performance of terrain type, vegetative cover, shell type, vehicle speed, magnet power, position and orientation of shell relative to the magnet, and magnet-to-ground distance are all investigated. Performance is seen to be very good for most shell types and the main factor affecting performance is seen to be magnet-to-ground distance. A number of recommendations for vehicle redesign and for operational procedures are also included. (U)

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1. INTRODUCTION

1.1 BACKGROUND

In Canada there appear to be a sufficient number of heavily contaminated ranges to warrant investigation of means to carry out clearance of only the surface of a range. Following a request by Director Military Engineering Operations (DMEO), the Mines and Range Clearance Group (MRCG) of the Defence Research Establishment Suffield (DRES) carried out a study of methods which automatically remove all ferrous metals from the ground surface. The findings of the study (Annex A) were that the best short term solution appeared to be a linear transverse array of existing stock magnets equipped with a load cell and pushed by an armoured vehicle. It was noted that such surface clearance methods would also be of use to reduce clutter interference as a preliminary step to utilizing UXO search systems. In that report, system requirements were determined, and a design concept together with schematic diagrams was then detailed for a system with five circular magnets

in a two row array of two and three, and for a system with three rectangular magnets. Circular magnets were recommended as having greater depth of field per unit weight. Magnet power and weight, estimated pickup distances, estimated costs, magnet suppliers and designers were all detailed. Finally, a long term solution, consisting of a continuous pickup and transfer mechanism such as a rotating drum magnet, was suggested but it was noted that extensive research and development would be required to put such a system on line. Thus, it was felt that the short term proposal should be pursued first and, based on the success of it, the longer term solution should possibly be pursued at a later date.

The prototype range clearance vehicle was designed by Mr. Charles Rose of DCMEM. The magnets consisted of three 114 cm DAWX circular electric lifting magnets each wound with a deep field aluminum strap coil (230 V nominal maximum rating). The magnets, manufactured by Ohio Magnetics and weighing 1273 kg apiece, were each held up by a three point chain suspension from a rhomboidal shaped steel frame. Raising and lowering of magnets was achieved by means of an electric winch and cantilever arm arrangement controllable from inside the cab. Power for winch and magnets was supplied by an Ohio Magnetics OPT 27.5-18 generator capable of supplying 27.5 kw and a GM 353 diesel engine, both of which were mounted on the rear of the vehicle. The vehicle chosen was a modified M4A2 Sherman tank. The turret had been removed, a plate welded over the turret opening to blank it off and a hatch installed in the blank off plate. Additional armouring was installed underneath the vehicle in the form of an armour steel sheet offset mounted from the hull by means of steel blocks. The additional armouring required blanking off the floor escape hatch and installing a new one rearward. Finally, a LEXAN window was mounted in front of the driver to improve hatch down visibility as compared to the standard periscope system.

Construction of the prototype system was carried out under the supervision of Sgt. D.E. Jones at the Land Engineering and Test Establishment (LETE).

A field program procedure (Annex B) for evaluation of the system was prepared by MRCG and, following consultations with Capt. D.B. Stevenson of CFB Calgary, Wainwright Detachment, the tests were scheduled

for the week of July 16 on GS 063510 at Camp Wainwright.

1.2 EVALUATION STRATEGY

The purpose of the evaluation was to determine the conditions under which unexploded ordnance (UXO) could be picked up by the system. A variety of parameters were expected to influence the system performance, specifically:

1. Shape and size of shell
2. Shape and size distribution of shrapnel
3. Amount of shrapnel on the ground
4. Amount of shrapnel on the magnet
5. Distance from shell to magnet
6. Terrain type
7. Vegetative cover
8. Relative shell to magnet position
9. Magnet traverse speed.

It was realized that ideally one should examine the combined effect of all influencing factors but this would require an enormous number of individual tests. Thus, it was considered necessary to examine the influence of each of the factors while maintaining the others constant. For those factors suspected of being strongly interconnected, tests combining the two would be performed. Sufficient time was also allotted to allow examination of any unforeseen influences.

The test objectives, then, were threefold, namely:

1. To establish the feasibility of the system by determining the limitations.
2. To determine an operating procedure to maximize system efficiency, if feasibility was established.
3. To determine modifications to the system which would enhance performance.

The actual tests and results are detailed in section 2. Many changes have been made to the procedure as detailed in the original FPP (ANNEX B). These were mainly due to the flexible nature of the FPP which

allowed elimination of many steps depending on specific results of other tests. Some changes were due to operational limitations of the vehicle such as maximum magnet clearance.

Observations and conclusions are found in section 3. A number of recommendations concerning the operation of the vehicle, modifications to the vehicle and recommendations of a general nature are found in section 4 together with a summary of the evaluation.

2. PROCEDURES

2.1 MEASUREMENT OF THE MAGNETIC FIELD DISTRIBUTION

The schematic diagram for a typical magnet showing the measurement parameters is given in Figure 1. The spatial variation of the magnitude of the magnetic field intensity, B was determined by orienting the probe of an RFL Industries Model 750A Hall Effect Gaussmeter until a maximum value occurred. Readings were obtained with the magnet power generator operating at 1600 rpm (210 V magnet voltage) and are plotted in Figure 2. The maximum field corresponding to $r = 18.4$ cm, $h = 0$ cm and the field at the magnet center ($r = 0$, $h = 6.4$) are shown for the three magnets in Table I. The generator speed is 1800 rpm (voltage 240 V at magnets) and for comparison the corresponding field values for magnet 1 (Figure 3) at 1600 rpm are also included. Reproducibility tests established a field strength uncertainty of approximately 0.2 to 0.5 kG (Kilogauss), presumably partially due to uncertainty in positioning by tape measure (0.5 cm) of the probe. Field attained maximum value after approximately 5 seconds.

2.2 CALIBRATION OF VEHICLE SPEED

Since the vehicle possessed two engines and hence two tachometers, it was found to be difficult to calibrate vehicle speed as a function of tachometer setting. Therefore, the vehicle was driven through a straight course at top speed in first gear, and then at top speed in second gear. Results are recorded in Table II.

2.3 STATIC VEHICLE MEASUREMENTS

With the vehicle stationary, tests were performed to determine the height above ground, "h", (see Figure 1) at which the magnets would cease to pick up a given shell type. Parameters are shown in Figures 1 and 3 and were chosen to span the expected range of encounters. For this and all further tests, parameter "r" was measured from magnet center to the center of mass of the shell and h was measured from the bottom face of the outer rim of the magnet to the ground surface on which the shell lay. Data are summarized in Table III. A "Y" implies that the shell was picked up with no hesitation, an "N" implies that the shell was not picked up and an "S" implies that the shell was picked up some of the time for those parameters in question. A number of shells, all flat on the ground, were tested in various orientations and heights at 210 V magnet voltage. Only the LAW rocket was tested at 240 V since it represented the worst case. The test was foreshortened since it was found in preliminary trials that pickup was easier for a moving magnet as opposed to a stationary magnet.

2.4 DYNAMIC VEHICLE PICKUP TEST

This test was performed on flat ground with minimal grass cover. Vehicle speed was 4.6 km/h (see section 2.2) and tests were conducted using magnet #1. Preliminary tests showed that shell orientation, α, and distance from magnet center, r, were not critical but, as a check, some measurements were performed at constant height varying these parameters. Results are summarized in Table IV.

Parameter h was chosen to span the range between marginal pickup height (~ 45 cm) and normal operating height (~ 30 cm). Likewise parameter r was chosen to span the width of the magnet (~ 54 cm).

In this and all other tests, except as noted, shells were laid flat on the ground.

2.5 MULTIPLE SHELL AND SHRAPNEL TEST

The effect of more than one shell and various amounts of shrapnel on magnet pulling power was investigated on bare flat ground. Heights chosen were close to normal operating height, but after the first four trials the front magnet was dropped one chain link to equalize heights above flat ground. Results are summarized in Table V. Since section 2.4 showed that orientation and distance from magnet center were not critical, these were chosen at random. Vehicle speed was 4.6 km/h. Coarse shrapnel was taken to be shrapnel whose pieces were approximately greater in area than 150 cm^2. Otherwise, shrapnel was considered to be fine. Shrapnel was always picked up prior to picking up the round. Magnet voltage was set at 210 volts throughout the test.

2.6 TEST ON HILLY GRASSY TERRAIN

This test was conducted to determine the operational capabilities on moderately hilly grassy terrain. A hill was chosen having a slope of approximately 1:24 with grass of approximate length 25 cm. The boom was lowered to normal operating height and magnet voltage was set at 240 V. Vehicular speed was 4.6 km/h except as noted, and all tests were performed going uphill as this imposed no serious constraints on operation. The results of individual trials are summarized in Table VI. After trial number five, it was suggested that the short headstart used might be affecting results by not allowing magnet swing to dampen out. Thus, trials 6-9 were initiated using longer headstarts.

2.7 TEST ON LEVEL SCRUB BRUSH COVERED GROUND

This test was conducted to determine operational capabilities on level, flat ground covered with thick scrub brush. The area chosen was flat enough to allow a good headstart and was relatively free of potholes. The scrub brush was approximately 45 cm high and sufficiently thick so that a

round placed under the scrub brush could not be seen from more than half a meter away. All rounds were wedged solidly under the brush. Magnet height was set to normal operating height and magnet voltage was set at 240 V. Vehicular speed was 4.6 km/h. The results of individual trials are summarized in Table VII.

2.8 TEST ON HILLY SCRUB BRUSH COVERED GROUND

This test was conducted to determine operational capabilities on hilly scrub brush covered ground. The area chosen had a slope of approximately 1:6 with frequent 8 to 10 cm deep depressions. The scrub brush was approximately 45 cm high and sufficiently thick so that a round placed under the scrub brush could not be seen from more than half a meter away. All rounds were wedged solidly under the brush and the brush was then tamped down over the round. The boom was lowered to the approximate operating height and magnet voltage was set at 240 V. Vehicular speed was 4.6 km/h and traversing was done both uphill and downhill as noted in Table VIII. The results of individual trials are summarized in Table VIII.

2.9 TEST ON PARTIALLY BURIED SHELLS

Although outside the mandate of the original task, it was decided to test the performance on partially buried shells. An area was chosen that had been dug up by the vehicle during previous tests. The area was fairly flat with sparse grass cover and with numerous depressions and mounds of approximately 10 to 20 cm depth and height. Shells were placed in the earth and completely or partially covered with dirt. In some cases the dirt was lightly tamped and in others it was heavily tamped. Vehicular speed was 4.6 km/h and magnet voltage was 240 V. Results are presented in Table IX. After the first three trials, it became obvious that height variations due to ground depressions and mounds were a major factor in lack of shell pickup. The tests were then moved to the site of the static vehicle tests which had very few mounds or depressions and thus ensured constant height.

3. OBSERVATIONS AND CONCLUSIONS

3.1 MEASUREMENT OF THE MAGNETIC FIELD DISTRIBUTION

The peak value of the magnetic field was found to be between 11 and 14 kG for a voltage of 240 V. It is difficult to translate this into a force per unit volume of iron since this requires a knowledge of the spatial derivatives with respect to a particular coordinate system. Figure 2 suggested that the fall-off of the absolute value of B with respect to radius, r, was roughly comparable to that with respect to height, h. In fact, pickup tests suggested that height dependence is much more critical than r dependence, which again points out that it is the field derivative values that are important. Although the field peaks at h = 0, r = 18.4 cm (Table I) there is no reason to assume that the force field peaks there.

It was seen that the current to the magnet must be left on for at least 5 s to ensure that the field builds up to a maximum. Table I shows that field values were comparable between the three magnets and thus the force fields should be the same, since they possess identical geometry. Table I also points out that there is a factor of approximately two in field strengths between operating the magnets at 240 V and operating them at 210 V, suggesting that at 210 V the magnet core has not saturated. For part of the tests, the magnets were operated at 210 V, since manufacturers specifications suggested operation at 75% duty cycle, presumbly to avoid magnet overheating. When no problems were encountered at this 87.5% duty cycle (nominal maximum voltage is 240 V), the voltage was upped to the maximum. Again no problems were encountered, but it should be noted that the magnets were probably on for no more than 50% of the time during the tests.

3.2 CALIBRATION OF VEHICLE SPEED

Vehicle speed was found to be 4.6 km/h at top speed in first gear and 9.8 km/h at top speed in second gear. The former was found to be a

more suitable speed for range clearance in terms of providing adequate driver reaction time and facilitating negotiation of more rugged terrain. It was also suggested by later tests that the higher speed might inhibit pickup of rounds since the impulse applied to the shells might decrease.

3.3 STATIC VEHICLE MEASUREMENTS

There appeared to be at most a slight effect on pickup capability due to shell orientation or distance from shell center to magnet center (r). Rather, the major effect on pickup appeared to be due to the distance from ground to magnet (h). These effects appeared to be borne out by later tests, as well.

Shells which were picked up struck the magnets with considerable force. Due to the inherent uncertainties in the detonation of UXO, it is not possible to determine how this would affect the probability of detonation.

In the case of the 155 mm shell at h = 51 cm, r = 36 cm it was seen that wobbling the shell slightly by hand in either a horizontal or vertical direction would allow the shell to be picked up when otherwise it would not be. The reason for this is unclear but may be related to the effect on the horizontal component of force caused by a change from static to dynamic friction.

Tests on the LAW rocket showed that it was substantially more difficult to pick up than the other rounds. This was not surprising since only the head of the rocket contained any ferrous material and, even then, not much of it. Tests on the LAW also showed that, in agreement with field measurements, there is substantial improvement in operating the magnets at the full rated voltage of 240 V.

Overall results show that, for a static magnet, assured pickup of all shells except a LAW rocket will occur for ground-to-magnet face heights less than approximately 43 cm (V = 210 V). For the LAW rocket, this height is approximately 25 cm.

3.4 DYNAMIC VEHICLE PICKUP TEST

Results from this test in many ways confirmed the static tests. Orientation, including the possibility of a $0^{0}/180^{0}$ difference, and radial distance from the magnet center did not appear to affect pickup performance, while the major influence on pickup was again found to be the height of magnet face above ground. This is not obvious from the curves of $|\vec{B}|$ versus h and r but in actual fact it is the field derivatives and their directions that determine the force and these cannot be deduced from the curves. The maximum assured pickup height (V = 210 V) for all shells except the LAW rocket was just under 51 cm as compared with 43 cm for the static case.

Tests on the LAW rocket, while again showing it to be the most difficult to pick up, produced more interesting results. At a magnet voltage of 210 V, pickup occurred at a height of 36 cm as compared with a maximum height of 25 cm for the static case. This, combined with the previous results, implied that motion of the magnets aided pickup. Increasing voltage from 210 V to 240 V again seemed to improve pickup performance.

It was seen for the marginal pickup cases that sometimes a speed between 0 and 4.6 km/h appeared to provide better pickup than 0 or 4.6 km/h. This suggests that there may be an optimum speed for pickup which is between 0 and 4.6 km/h. Some shells which were missed while going forward were picked up as the vehicle slowly backed up. Since the vehicle usually halted just after missing a round, it is thought that this enhanced pickup is due to sway of the magnet caused by initial acceleration backwards. This in effect decreases magnet-to-ground height and can increase spatial field derivatives.

It was noted that, for marginal cases concerning large shells well off center of the center magnet, if that magnet failed to pick it up, most often the disturbance of the shell by the magnetic field would cause it to roll and be picked up by the outer magnets. This increases confidence that the magnets do not have a "dead zone" between them, for large shells at least.

3.5 MULTIPLE SHELL AND TARGET SHRAPNEL TEST

In general, shrapnel and multiple shells had negligible effect on pickup performance at normal operating height presumably due to the high contact load capacity of the magnets. At the height of 30 cm virtually everything but the LAW rockets was picked up. Although two 40 mm shells were missed on trial number 8, video tape replay showed that a bump in the track caused the magnets to increase in height by approximately 15 cm just prior to passing over the shells. This would have made the height of the magnet approximately 47 cm above the ground which is almost at the marginal limit. Clearly, the height of magnet above ground was again the most important factor. A height of 30 cm for the back magnets appeared to be reasonable since this placed all three magnets at approximately the same height and assured good pickup (excepting the LAW rocket).

At this point a few words should be said about the LAW rocket. The complete dummy LAW round was found to be difficult to pick up compared to other rounds. Pickup of the head alone was found to be significantly easier than the complete round, which is noteworthy since LAW blinds virtually always consist of just the head, often without the nose cone. Both the tail piece and nose cone add only deadweight since neither is ferrous, and thus pick up of a complete LAW round is not considered a valid test. On the other hand, pickup of the head only is not a valid test since the round contains no material to simulate the weight of the explosive. The explosive weight of between 0.2 to 0.5 kg makes up a considerable fraction of the weight of the very light head and thus may significantly affect pickup of it. It is not clear whether the weight of the tail compensates for the lack of explosive, particularly since this weight would be far from the center of mass of the head alone. Thus, it is felt that the tests on the LAW round should be repeated using the head only with a simulant explosive fill. Complete LAW rounds were still used in other tests as their pickup clearly represented a worst case.

Finally, it should be stated that trial number 9, consisting of approximately 100 kg of coarse and fine shrapnel ($\sim$ 40,000 cm^3 total)

plus one shell (81 mm) represents the most typical case, namely a dense distribution of shrapnel with comparatively few shells. For this case, there was no problem picking up both shrapnel and shell.

3.6 TEST ON HILLY GRASSY TERRAIN

Hilly grassy terrain imposed no adverse constraints on pickup, except for areas with large dips which could increase the magnet to round distance. All typical rounds, except the LAW rocket, were easily picked up. Some shells that were missed going forward were picked up going slowly backward. The vehicle had no trouble negotiating the hill at 4.6 km/h and slower speeds did not suggest an optimum. Trials 5 to 9 were used to determine if a short head start was detrimental to pick up (presumably due to the lifting of the magnets caused by the initial acceleration). There does appear to be some effect on the marginal pickup of LAW rounds, but this will normally not be a worry since, if necessary, the vehicle can back up after dumping prior to moving forward. The distance from the center of the LAW rounds in trials 8 and 9 does not affect the above conclusion, since previous tests have shown that, at the heights in question, radius does not significantly affect pickup.

3.7 TEST ON LEVEL SCRUB BRUSH COVERED GROUND

Results of this test showed that thick scrub brush 45 cm high had negligible effect on pickup of rounds, one of which was even jammed into the ground. This is a tremendous advantage over clearance of such land on foot, since the rounds are almost impossible to see until one is directly over them. Even then, a khaki coloured round is very difficult to see, particularly if one's attention is slightly wandering.

As usual, pickup of LAW rockets was a problem.

3.8 TEST ON HILLY SCRUB BRUSH COVERED GROUND

At a nominal magnet-to-ground distance of 25 cm all shells with

the exception of the LAW rocket were picked up. The hill, which was much steeper than that of the test on hilly grassy terrain, and the scrub brush did not appear to have any detrimental effect on pickup of shells.

3.9 TEST ON PARTIALLY BURIED SHELLS

Results of tests on partially buried shells were generally quite disappointing. On the first area, where magnet height was uncertain, cause of the inability to pick up shells could not necessarily be assigned to the fact that they were buried. Under more controlled conditions on the second area, it was seen that burying the shells did adversely affect pickup. It should be remembered, however, that part of the effect of burying shells is to increase shell to magnet separation by as much as 15.5 cm for a 155 mm shell just under the surface.

Ability to pick up partially buried or buried shells depends quite critically on soil type, degree of compaction, moisture content and the amount of time that the shell has been in the ground. Performance, then, is best determined in actual field use by recording rounds missed together with the pertinent environmental conditions during actual operation.

3.10 OVERALL VEHICLE PERFORMANCE AND PROCEDURES

The vehicle was able to negotiate all chosen terrain types with ease. Low hills and potholes caused no trouble. Downhills produced some problems with braking and sway of the magnets. This latter effect could cause an increase in magnet-to-ground separation and downgrade pickup performance.

Turns did not cause serious problems for speeds less than 5 km/h although some magnet sway was noted.

Dumping of shells and shrapnel again posed no major problems. All shells and shrapnel released easily without clinging. Calibration of the load cell for determining when to dump should be done on the particular

range to be cleared, since the size and shape of typical shrapnel is as important as weight in as far as it interferes with shell pickup.

4. SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

The range clearance magnetic pickup vehicle performed very well. At reasonable ground-to-magnet distances of about 30 cm, it picked up all shells and shrapnel easily, the LAW rocket head fairly easily, the complete LAW round with difficulty and partially buried shells with difficulty. The pickup of the latter three classes of items was particularly encouraging since the LAW round has very little ferrous material in it and since the original mandate did not require pickup of partially buried shells. Terrain type, shell position and orientation had only minor effects on shell pickup. The vehicle should assist considerably in the surface clearance of contaminated ranges, particularly scrub brush covered areas where hand clearance is very difficult. It should be noted, too, that the ability to pick up shrapnel will minimize injury to personnel by contact with sharp metal and will expedite future clearance operations by reducing the amount of ferrous contamination present.

A number of recommendations have been formulated based on these tests and they can be categorized as relating to either vehicle redesign, operational procedures, or general recommendations.

4.2 VEHICLE REDESIGN RECOMMENDATIONS

The main concern with respect to vehicle design has been seen to be maintaining constant magnet-to-ground height (approximately 30 cm is ideally recommended). Since dips and bumps can alter this distance and adversely affect pickup performance, some method is required to stabilize the height. One suggestion would be a series of adjustable height outrigger wheels on the magnet assembly which would support a portion of the

magnet weight sufficient to allow the assembly to follow the terrain. The weight supported by the wheels could also be made light enough to prevent digging in of the magnet assembly.

Magnet sway also affects the ground-to-magnet height and force field distribution at the ground surface. Shock absorber units mounted between each of the three magnets would reduce such sway.

Mathematical modelling of the magnetic force field distribution would be warranted to determine whether altering magnet polarities (all were the same for these tests) or redesigning the magnets would increase field penetration and increase field between magnets. This work could be carried out either by DRES or, preferably, under contract by one of the major magnet companies.

Movement of the shell was seen to improve pickup and the possibility should be investigated of utilizing pulsed fields to facilitate such movement and at the same time reduce magnet duty cycle to the recommended 75%. As an alternative, a low force flail or even a nylon finger-skirt might be mounted in front of the magnet assembly.

It was seen that operating the magnets at 240 V significantly improved performance and hence this is the recommended voltage to use. The manufacturer, however, recommends operation at 75% duty cycle and thus should be contacted to determine the effects of operation at higher duty cycles.

Improvement of the braking system is desirable for negotiating downhills since these posed considerable difficulties for the driver.

4.3 RECOMMENDATIONS CONCERNING OPERATIONAL PROCEDURES

These can best be stated in point form.

1. Magnet current must be switched on for at least 10 seconds prior to attempting pickup of any objects.
2. Speed should be less than approximately 5 km/h. Pickup performance is adequate in this range and this is a comfortable operating speed for normal terrain. At the same time, such speeds allow

manoeuvrability and avoidance of obstacles while reducing magnet swing and the chance of digging a magnet into the soil. Although there may be an optimum speed to assist pickup, it is felt that it would be too difficult to maintain the vehicle at a speed much more precise than "0 to 5" km/h range.

3. A magnet-to-ground distance of between 25 and 30 cm is recommended and chains should be adjusted to ensure that all three magnets are at roughly this same height range for operation. For very rough terrain it may be necessary to increase height. (Here again, an outrigger wheel support system would automatically compensate for terrain roughness.)
4. After dumping or halting, the vehicle should be backed up approximately 10 m prior to moving forward again. This will reduce any possibility of the magnets rising on initial acceleration.
5. Moderate amounts of shrapnel on the magnets do not affect pickup. Determining when to dump the magnets is a problem that can only be solved for a particular range at the time of clearance since size, shape and weight of shrapnel are all pertinent factors. The first few kilometers of a range should be cleared while frequently stopping and checking the magnet to see how much metal is being picked up. When metal starts to be missed, the reading on the load cell, together with the distance traversed, should be recorded. If, after a few dumps, the distance traversed between dumps is reasonably consistent, the vehicle can be driven that distance prior to dumping. If the load cell readings are also con-

sistent, it too, can be used as an indicator of when to dump.

6. Dumping of magnets should be done by dropping the debris in a cleared area, so that the vehicle will not run over it again. For sweeps other than the first, the vehicle need only turn slightly and drop debris in the cleared area on one side of it. For the first sweep, of course, the vehicle must turn and drop debris behind it. It should be dropped a distance greater than 10 m behind where it stopped (see point number 4).
7. Dumping in scrub brush covered areas should be done more often than bare areas, since there is no way to see how much material is on the magnets.
8. Traverse downhill should be avoided where possible due to magnet sway and braking difficulties.

4.4 GENERAL RECOMMENDATIONS

Driver technique will probably be a major factor in overall clearance performance. Since development of an optimum technique will require much interaction between machine and operator, it is recommended that one driver should operate the vehicle initially and until such a technique is fixed.

Before modifications as suggested in section 4.2 are carried out, extensive clearance operations should be undertaken to determine any additional limitations on operation and to lay down additional specific operational procedures. It must be emphasized that such trial clearance operations are NOT merely to clean up ranges but must be carried out under controlled conditions with a number of observers to note what types of rounds are missed on what terrain type. Positions and orientations of rounds, proximity to the magnet sweep path, vegetative cover, degree of magnet sway and shrapnel load on magnets must all be noted. Such operations can also be used to determine the ability of the machine to pick

up partially buried shells as they naturally occur. If these operations indicate that explosions do not occur or that only small shells detonate, it may be feasible to employ a lighter vehicle such as a bulldozer equipped with an armoured cab and to tow the magnet array rather than push it.

Further tests on the LAW rocket heads loaded with a simulant explosive to ensure proper weight should be conducted. Tests should be performed at this time to determine if clearance can be carried out on much denser and higher scrub brush.

Only after such in-field operations can modifications to the machine be made and the feasibility of a continuous feed system be evaluated.

TABLE I

Magnetic Field Measurement

Magnet Number (Fig. 3)	Magnet Voltage (volts)	Magnetic Field at Magnet Center (r = 0, h = 6.4 cm) (kg)	Maximum Field (r = 18.4 cm, h = 0) (kg)
1	210	2.7	6.0
1	240	5.2	14.0
2	240	4.9	11.4
3	240	4.6	12.8

TABLE II

Vehicle Speed Calibration

Distance (m)	Time (s)	Speed (km/h)
80	63.0	4.6
80	29.5	9.8

TABLE III

Static Pickup Test

Shell [1] Type	Magnet Voltage (Volts)	h (cm)	r (cm)	α (o)	Result [2]	Comments
155 mm	210	79	0 0 0 36 36	0 45 90 0 90	N N N N N	
155 mm	210	64	0 0 36 36	0 90 0 90	N N N N	
155 mm	210	51	0 0 36 36	0 90 0 90	N N S S	Shell is picked up if slightly wobbled by hand
155 mm	210	43	0 0 0 36 36	0 45 90 0 90	Y S S Y Y	
155 mm	210	<43	-	-	Y	All combinations of above parameter values
106 mm	210	51	-	-	S	All combinations of above parameter values
60 mm	210	51	-	-	Y	All combinations of above parameter values
LAW	210	38 25	- -	- -	N Y	All combinations of above parameters
LAW	240	43 38	0 36 -	0 0 -	S S Y	Not picked up on first pass, but was picked up when vehicle backed up All combinations of above parameters

1. Shells are described in Table X

2. Y - Pickup achieved; N - Pickup not achieved;
S - Pickup achieved on some trials but not others

TABLE IV

Dynamic Vehicle Test

Shell Type	Magnet Voltage	h (cm)	r (cm)	α (o)	Results	Comments
155 mm	210	36	0	0	Y	
			31	0	Y	
			48	0	Y	
			0	90	Y	
			31	90	Y	
			48	90	Y	
		43	0	0	Y	
			48	90	Y	#1 magnet moved shell initially, #3 magnet captured it
		51	0	0	S	
81 mm	210	36	48	0	Y	
		43	48	0	Y	
3.5 inch rocket	210	36	48	0	Y	
		43	48	0	Y	magnet moved shell outward, then it rolled in and was captured
LAW	210	36	0	0	Y	
			48	0	Y	
			48	90	Y	
		43	0	0	N	
			48	90	N	
	240	38	0	0	Y	
			36	0	Y	
		43	0	0	S	
			36	0	S	
40 mm	210	43	48	0	Y	#1 magnet moved shell initially, #3 magnet captured it

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TABLE V

Multiple Shell and Shrapnel Tests

Trial #	Ave. Magnet 1 h (cm)	Ave. Magnet 2 h (cm)	Ave. Magnet 3 h (cm)	Magnet [1]	Shell Type	r (cm) [2]	θ (°)	Magnet	Shrapnel Type	Shrapnel Volume (cm^3)	Results Shell	Results Shrapnel	Comments
1	40	30	30	1	155 mm	48	0	1	Fine	33000	Y	Y	Base of round picked up first - round was dragged somewhat but firmly attached
2	40	30	30	1	155 mm	48	90	1	Fine	33000	Y	Y	
3	40	30	30	1	155 mm	5	45	1	Fine	11000	Y	Y	Rounds were spread out randomly along vehicle path
				2	81 mm	15	90	2	Fine	11000	Y	Y	Shrapnel was scattered at random
				3	3.5 inch	20	0	3	Fine	11000	Y	Y	Head of 40 mm was pounded 2.5 cm into ground
				3	LAW	40	0				N	-	
				2	40 mm	20	0				Y	-	
4	40	30	30	1	155 mm	5	45	1	Fine	11000	Y	Y	Same as 3 except shrapnel was clumped on top of 3.5 inch, 40 mm and 155 mm rounds in equal amounts
				2	81 mm	15	90	2	Fine	11000	Y	Y	
				3	3.5 inch	20	0	3	Fine	11000	Y	Y	
				3	LAW	40	0				N	-	
				2	40 mm	20	0				Y	-	
5	32	30	30	1	155 mm	5	45	1	Fine	11000	Y	Y	Same as 4
				2	81 mm	15	90	2	Fine	11000	Y	Y	
				3	3.5 inch	20	0	3	Fine	11000	Y	Y	
				3	LAW	40	0				N	-	
				2	40 mm	20	0				Y	-	
6	32	30	30	3	LAW	40	0	-	-	-	Y	-	
7	32	30	30	1	155 mm	5	45	1	Fine	11000	Y	Y	Same as 4 but just the LAW rocket head used. 155 mm plowed the ground for about 50 cm. LAW head is front end of rocket (the way they are normally found). Explosive weight is not simulated
				2	81 mm	15	90	2	Fine	11000	Y	Y	
				3	3.5 inch	20	0	3	Fine	11000	Y	Y	
				3	LAW head	40	0				Y	-	
				2	40 mm	20	0				Y	-	
8	32	30	30	1	155 mm	10	45	1	Fine	11000	Y	Y	LAW head was flattened. Complete LAW round was near outer edge of magnet. Magnets raised approx. 15 cm prior to passing over the 2-40 mm. shells that were missed, due to a large bump in the track. Shrapnel was uniform along 20 m track length except for clumps around the 3.5 inch, third 40 mm and LAW head. Shells were also uniformly distributed along track. 3.5 inch had nose cone separated.
				3	3.5 inch	0	45	2	Fine	11000	Y	Y	
				1	LAW	5	45	3	Fine	11000	N	Y	
				2	LAW head	0	90	1	Coarse	27000	N	Y	
				1	20 mm	55	45	2	Coarse	27000	Y	Y	
				1	20 mm	55	45	3	Coarse	27000	Y	Y	
				1	40 mm	10	90				N	-	
				1	40 mm	20	90				N	-	
				1	40 mm	5	90				Y	-	
				?	40 mm	?	?				Y	-	
				?	40 mm	?	?				Y	-	
				?	40 mm	?	?				Y	-	
				3	106 mm	25	45				Y	-	
				1	81 mm	25	0				Y	-	
				1	60 mm	10	90				Y	-	
9	32	30	30	1	81 mm	0	0	1	Fine	11000	Y	Y	
								2	Fine	11000	-	Y	
								3	Fine	11000	-	Y	
								1	Coarse	27000	-	Y	
								2	Coarse	27000	-	Y	
								3	Coarse	27000	-	Y	

1. Denotes magnet that shell or shrapnel passed under

2. Relative to magnet shell was under

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TABLE VI

Hilly Grassy Terrain Test

Trial #	Magnet[1.]	Height h (cm)	Shell Type	r (cm)[2.]	α (°)	Result	Comments
1	3	40	105 mm	0	90	Y	105 mm, LAW and 40 mm were in a 10 cm deep depression
	3	30	81 mm	0	90	Y	81 mm was encountered 3 meters after other three shells
	2	40	40 mm	0	0	Y	Speed was substantially less than 4.6 km/h
	1	40	LAW	15	0	N	3 m headstart
2	3	40	LAW	15	0	Y	Speed was 4.6 km/h - 3 m headstart
3	3	40	LAW	0	90	S	Missed going forward at 4.6 km/h. Picked up going slowly backward 3 m headstart
4	3	38	LAW	0	90	Y	Repeat of trial 3 after slightly lowering magnets. 3 m headstart
5	3	38	LAW	0	90	S	Same as trial 4. Missed going forward at 4.6 km/h. Picked up going slowly backwards 3 m headstart
6	3	36	LAW	0	0	Y	10 m headstart
7	3	36	LAW	0	90	Y	10 m headstart
8	3	36	LAW	45	0	N	5 m headstart
9	3	36	LAW	45	90	N	5 m headstart

1. Denotes magnet that particular shell passed under
2. Relative to magnet that shell was under

TABLE VII

Test on Level Scrub Brush Covered Ground

Trial #	Magnet [1]	Height h (cm)	Shell Type	r [2] (cm)	α (^{o})	Result	Comments
1	1	37	81 mm	0	0	Y	
2	2	38	105 mm	0	90	Y	
3	3	38	40 mm	0	0	Y	Nose was wedged 2.5 cm into the ground and well under the brush
4	1	38	LAW	0	45	Y	The head was pulled off the LAW body
5	1	38	LAW	0	45	N	The round remained intact
6	1	38	40 mm	31	0	Y	
7	1	38	105 mm	31	0	Y	

1. Denotes magnet that particular shell passed under
2. Relative to magnet that shell was under

TABLE VIII

Test on Hilly Scrub Brush Covered Ground

Trial #	Magnet[1]	Height h (cm)	Shell Type	r[2] (cm)	α (^{0})	Result	Comments
1	1	25	105 mm	0	0	Y	Uphill run
2	1	25	105 mm	0	90	Y	Uphill run
3	1	25	40 mm	0	0	Y	Uphill run. Nose jammed 2.5 cm into dirt
4	1	25	81 mm	0	0	Y	Uphill run
5	1	25	40 mm	30	0	N	Uphill run. Short headstart ($\sim$ 2 m) apparently caused magnet to rise significantly
6	1	25	40 mm	30	0	Y	Uphill run 5 m longer headstart than trial #5
7	1	25	LAW	0	0	Y	Uphill run
8	1	25	40 mm	55	0	Y	Downhill run. Magnet sway caused round to roll to magnet #2 which then caught it. Round was originally set up to be 30 cm off center
9	1	25	40 mm	30	0	Y	Downhill run. Repeat of trial #8. On backing up magnets dug in. Difficult to brake going downhill
10	2 1	25 25	LAW 105 mm	0 50	45 0	N N	Downhill run. Number 1 magnet dragged 105 mm and flipped it into area between magnets 1 & 2
11	1	25	105 mm	30	0	Y	Downhill run
12	1	25	LAW	0	45	N	Downhill run.

1. Denotes magnet that particular shell passed under.
2. Relative to magnet that shell was under

TABLE IX

Test on Partially Buried Shells

Trial #	Magnet	Height h (cm)	Shell Type	Result	Comments
1	1 1 1 1 2 2	40-50 40-50 40-50 40-50 40-50 40-50	40 mm 40 mm 40 mm 40 mm 81 mm 105 mm	N N N N Y N	See Figure 4 (Shell a) See Figure 4 (Shell b) See Figure 4 (Shell c) See Figure 5 (Shell d) See Figure 6 Due to vehicle churning up soft earth, height was uncertain See Figure 7
2	1 1 1 1 2 2	40-50 40-50 40-50 40-50 40-50 40-50	40 mm 40 mm 40 mm 40 mm 81 mm 105 mm	N N Y Y Y N	Repeat of trial 1. Same positions and orientations. As tank approached from slightly different direction, depressions and mounds caused magnet swaying, rising and falling.
3	1 1 	30-40 30-40 30-40	40 mm 40 mm 105 mm	N Y N	Shell wobbled but wasn't picked up Magnet height again uncertain
4	1 1 2 2	50 40 45 45	105 mm 81 mm 40 mm 40 mm	N Y Y Y	See Figure 8 See Figure 9 Trials 4 - 7 were on more level, harder packed ground than tests 1-3. Thus heights could be more accurately fixed.
5	1 1 2 2	50 40 45 45	105 mm 81 mm 40 mm 40 mm	N Y N Y	Repeat of trial 4.
6	1	50	105 mm	N	Same positioning as trial 4.
7	1	30	105 mm	Y	Same positioning as trial 4.

TABLE X

Characteristics of Typical Rounds

SAMPLE DESCRIPTION

Sample No.	Type	Approx. Weight (kg)	Length (L) (cm)	Approx. Max Radius (R) (cm)	L/R	Estimate Depth (cm)
1	20 mm projectile facsimile	0.1	7.6	1.0	7.6	0-30
2	40 mm projectile facsimile	0.9	13.3	2.0	6.7	0-30
3	60 mm mortar	1.4	17.8	3.0	5.9	0-30
4	81 mm mortar	3.2	27.9	4.0	7.0	0-150
5	105 mm howitzer projectile	14.4	40.6	5.3	7.7	0-190
6	3.5 inch rocket	4.0	58.4	4.5	13.1	0(few cms)
7	66 mm rocket (LAW)	0.7	50.8	3.3	15.4	0-30
8	4.2 inch chemical projectile	6.4	31.8	5.3	6.0	0-100
9	155 mm howitzer	43.0	71.1	7.8	9.2	0-200

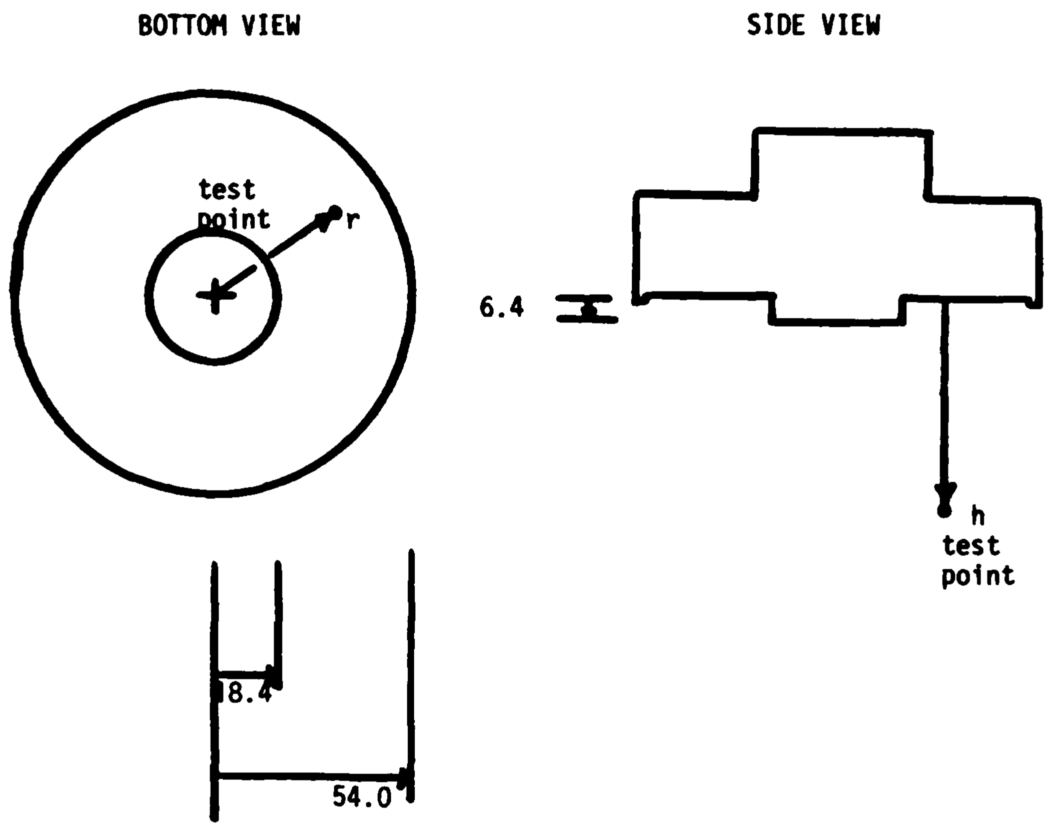

Figure 1: Magnet geometry. Distances are in cm.

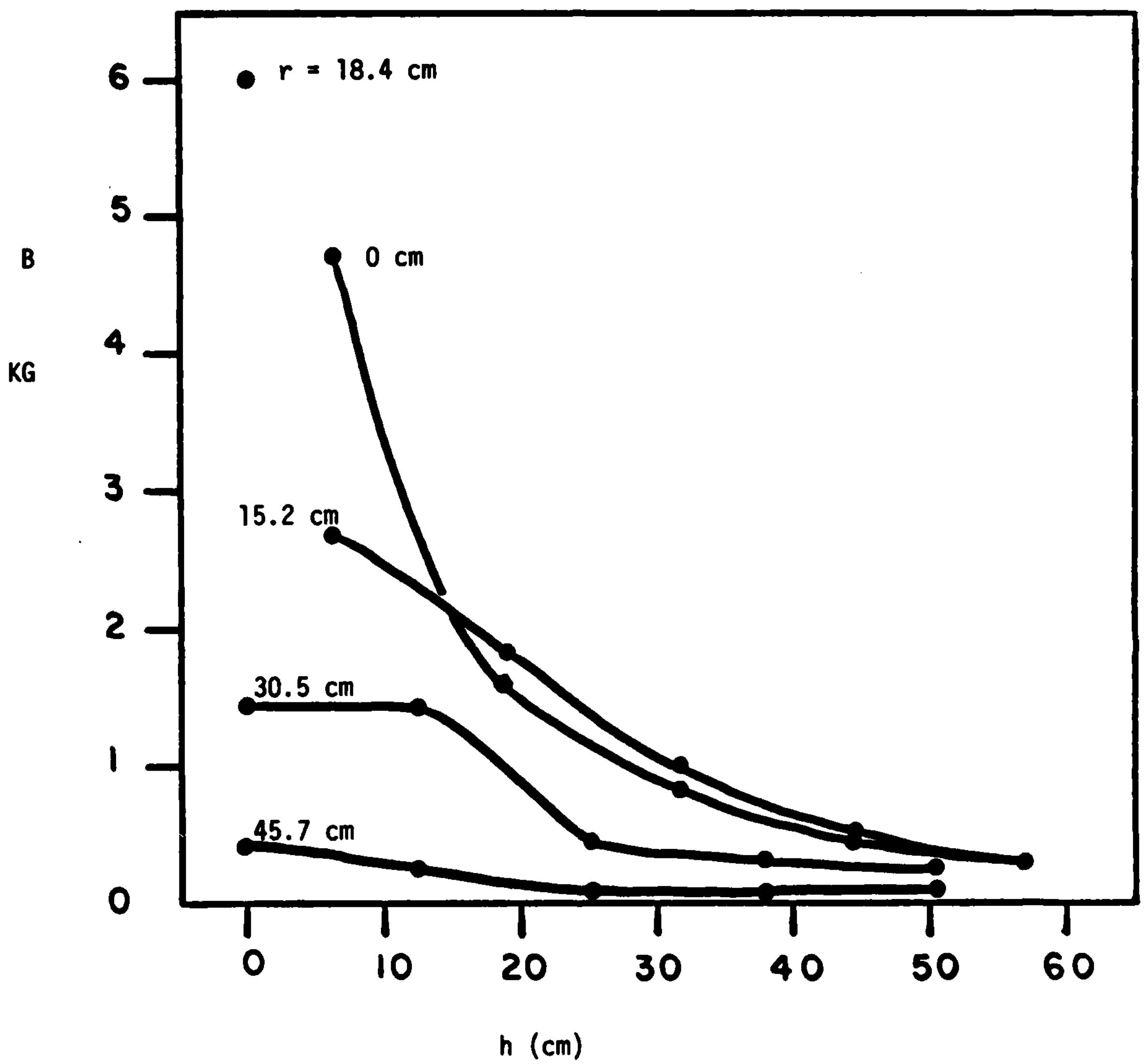

Figure 2: Absolute Value of Magnetic Field of Magnet 1 vs. Radius, r, and Depth h. See Figure 3 for geometry. Magnet voltage is 210 V.

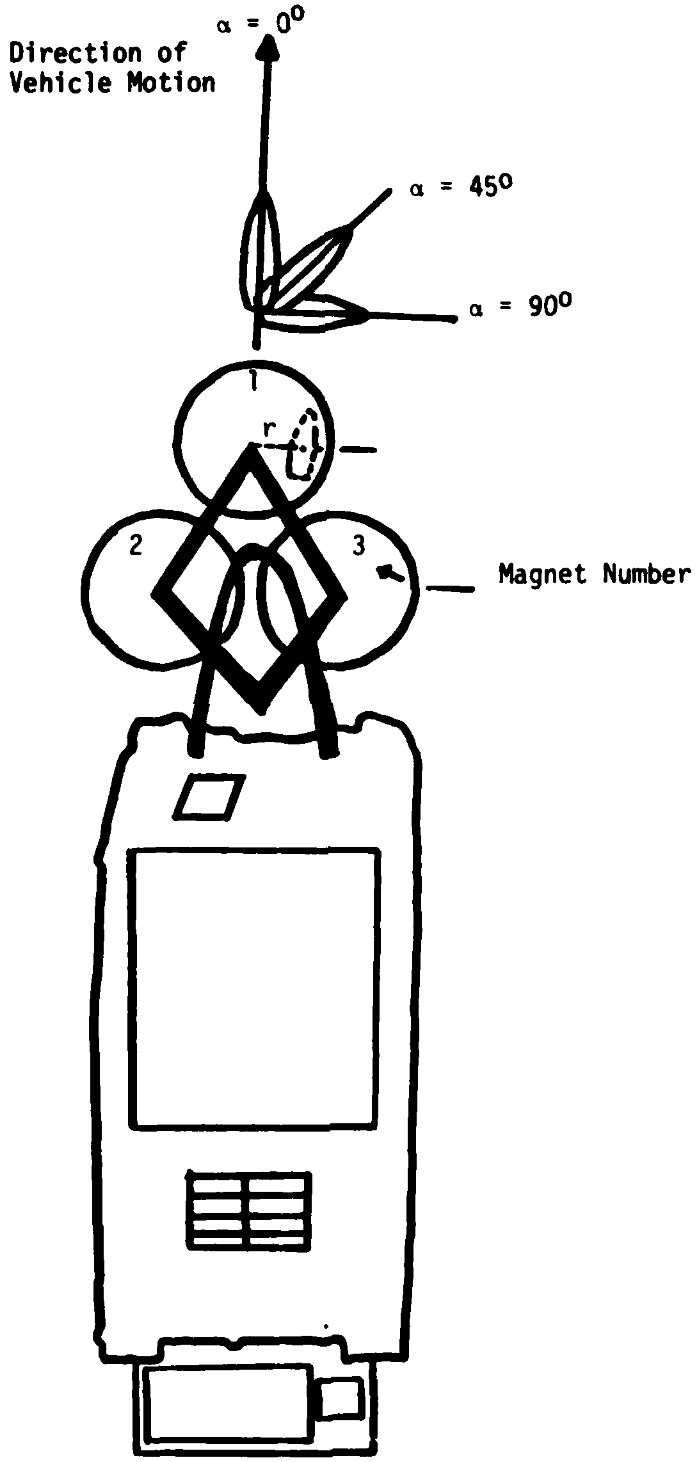

Figure 3: Parameters and schematic top view for magnetic pickup tests.

FIGURE 4. THREE PARTIALLY BURIED 40MM SHELLS. LEFT AND RIGHT HAND SHELLS CORRESPOND TO "C" AND "B" OF TRIAL 1 TABLE IX. SHELL "A" OF THE SAME TRIAL IS BETWEEN THE TWO AND BURIED SO AS TO BE INVISIBLE.

FIGURE 5. PARTIALLY BURIED 40MM SHELL. CORRESPONDS TO SHELL "D" OF TRIAL 1, TABLE IX.

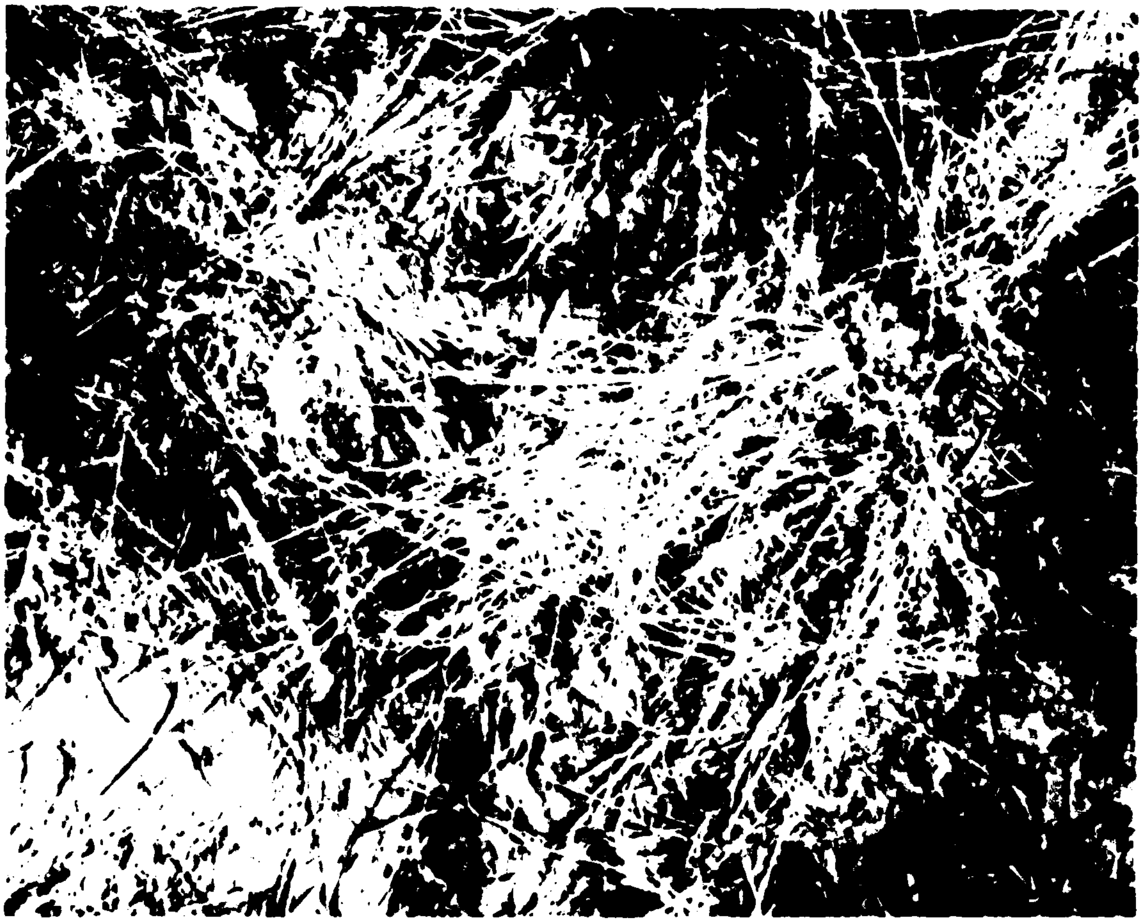

FIGURE 6. PARTIALLY BURIED 81MM MORTAR ROUND CORRESPONDING TO TRIAL 1, TABLE IX.

FIGURE 7. PARTIALLY BURIED 105MM SHELL CORRESPONDING TO TRIAL 1, TABLE IX.

FIGURE 8. PARTIALLY BURIED 105MM SHELL CORRESPONDING TO TRIAL 4, TABLE IX.

FIGURE 9. PARTIALLY BURIED 81MM SHELL CORRESPONDING TO TRIAL 4, TABLE IX.

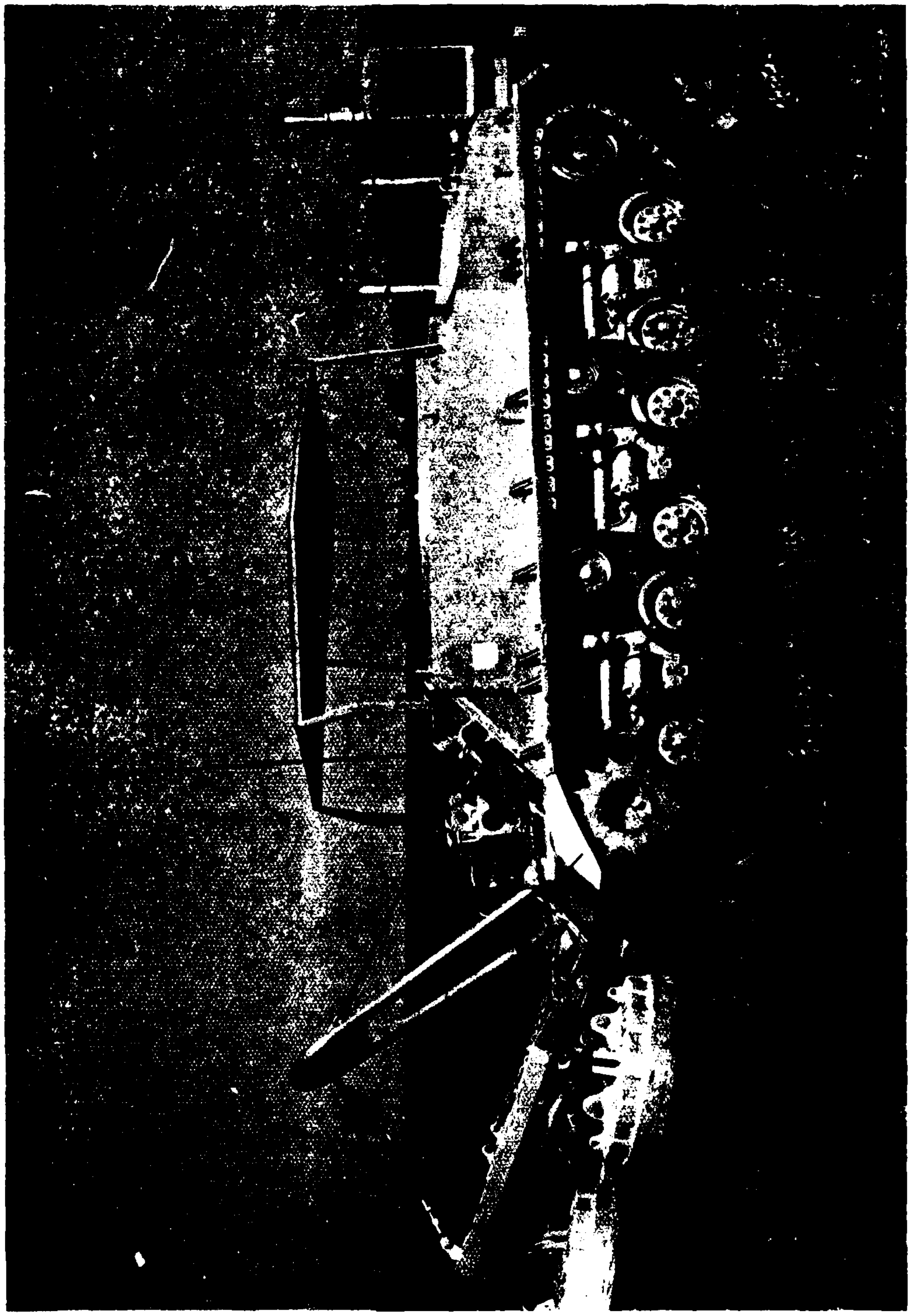

FIGURE 10. SIDE VIEW OF THE PROTOTYPE MAGNETIC SURFACE CLEARANCE VEHICLE

ANNEX A

Letter Report by J.E. McFee and Y. Das

DRES 3621H-1(SS), 7 Sept. 1978

It has been deemed by DMEO that there exist a sufficient number of training areas in Canada that are so contaminated with UXO as to make surface range clearance techniques feasible. Thus, following a request by DMEO, methods have been investigated which could automatically remove all ferrous metals from the ground surface. Such methods would also be of much use as a preliminary step on heavily contaminated ranges prior to implementing UXO search techniques.

Based upon correspondence with a number of agricultural machinery manufacturers and agricultural mechanics research establishments, it was decided that rock pickers and other such farm machinery would be of limited use primarily due to their inability to function properly on uneven or unplowed terrain.

Electromagnets were seen to be a possible solution to the problem, following successful preliminary tests at a local salvage yard utilizing an electromagnet with a nominal 1 ton load capacity (for a flat plate on contact with the pole face). Contacts were established with a variety of magnetics firms (Appendix 1) and an exchange of information has taken place and is continuing. From these discussions have emerged two possible solution paths:

1) a linear transverse array of existing stock electromagnets, with strain gauge load detectors, pushed by an armoured vehicle. This is a short term proposal and requires limited R&D and is intended to be available by summer 1979.
2) Long term solution. This would be a continuous pick-up and transfer mechanism, probably of a rotating drum design. This would require extensive R&D in two stages - firstly the design of the drum transfer mechanism and later the design of an attachment to sort shells and shrapnel.

We will concentrate in this brief on the former solution since its timing is more in line with the immediate task objectives as stated in WUD 21H52. It is recommended, however, that the latter solution be pursued, drawing upon the expertise of the firms in Appendix 1, after delivery

of the short term system.

Several requirements were established for the short term system:

1) It must be capable of picking up cylindrical or tear drop shaped UXO ranging in weight from approximately 100 grams to 50 kilograms. In this regard it was found that circular cross section magnets would have a larger depth of field for a given weight compared to rectangular magnets.

2) It must be able to pick up such rounds from a distance of at least 0.20 meters. This distance is based on the fact that underbrush or other vegetation will be present even on flat ground, thus preventing intimate contact between round and pole face.

3) The magnet would be pushed by an armoured vehicle. A Sherman Tank weighing approximately 29700 kg was suggested by DMEO as being available.

4) Width of sweep would be at least that of the vehicle. Since a Sherman Tank has a width of 2.62 meters and magnets of usable strength are usually a nominal minimum of 1.22 meters in diameter, a minimum of 3 magnets in a linear array would be required if they were rectangular. For circular magnets, it might be necessary to use five magnets to cover the path that would be missed by three in line magnets. Such arrays are preferred to a single long magnet in order that a uniform clearance could be maintained over uneven terrain. In addition, this may mean less overall damage in the event of a small local explosion.

5) Limiting speed would presumably be determined by the magnetic field distribution as it affects the UXO transit time from the ground to the magnet. Obviously, the faster the scanning speed the better, although a value of approximately 3.2 to 5.4 kph would be satisfactory.

6) A minimum of operator input is essential due to the finite human attention span. In particular, an automatic indicator of the effective remaining pickup power of the magnet is desired. One rough estimator of this could be an acceleration compensated strain gauge or load cell which could be included to tell the operator when the load on the magnet was such as to require dumping. This would ensure that the magnet would have adequate pickup power when any piece of UXO was encountered.
7) The magnets must be strong enough to witstand the force of exploding UXO. This might be achieved by the natural strength of the magnet or armouring it. Alternatively, the magnet might be cheap enough to be replaceable. It is expected that UXO detonations might destroy the suspension system. If this were a chain mount, however, downtime and repair cost could be minimal.
8) Power requirements should be low enough as to be portable on the pushing vehicle.

It cannot be emphasized strongly enough that the abilities of such a device for picking metal partially buried in soil or dense vegetation are unknown. These abilities should be assumed to be non-existant until testing proves them otherwise.

Of the companies contacted, the most affirmative response was received from Reyrolle Parsons of Canada Ltd. (Calgary), a Canadian outlet for Hi-Flux Magnets Ltd. (U.K.). The company has expressed an interest in designing and engineering a complete magnetic surface clearance system.

The basic system envisioned by Hi-Flux Magnets Ltd. would consist of a number of off-the-shelf rectangular magnets mounted side by side on a frame to be attached to the front of a tank. The particular model of magnet suggested would each have a 1.22 meter wide sweep, would have a mass of 3,859 kg, would consume 4.75 kw of power and would have approximate dimensions of 1.13 m by 1.07 m by 0.79 m. This type of mag-

net would pick up shrapnel and all ferrous shells up to 50 kg from a distance of 30-30 cm. The usable sweeping speed has been estimated to be 4.37 km/hr. The system would also include some kind of load-cell arrangement to periodically weigh the magnet plus accumulated debris (with the vehicle stationary) and warn the operator to dump the excess weight. A suitable generator and all necessary control electronics would also be provided. The stock magnets are already encased in 8.25 cm thick steel on the sides and 1.25 cm thick steel on the bottom. Additional armouring, if necessary, can be provided.

The number of individual magnets to be used would depend on the total sweep width desired, the total weight that can be safely supported by the mechanical linkage to the tank and the cost. The initial suggestion from Hi-Flux is to use three magnets to cover a 3.66 m wide track. However, the magnets alone would weight about 11577 kg. This load, added to the weight of the magnet frame and collected debris, may prove to be too much to be conveniently supported from the tank. However, since the width of a Sherman tank is about 2.62 m, the use of only two magnets (7718 kg) to cover a 2.44 m track may be adequate. Any problem due to the small uncovered width (0.18 meters) of the tank could be overcome by proper sweeping strategy. Alternatively, it might be possible to reduce the estimated 30 to 40 cm depth of field by the use of lighter magnets.

As regards to the cost of the system, Hi-Flux has so far provoided only the price of the magnets which is $15K per magnet. Following is a very rough guess at the cost of a two magnet system:

(i)	2 magnets @ $15K each	$30K
(ii)	Generator and Control Electronics	6K
(iii)	Design and Misc. Hardware	4K
	Total	$40K

A positive response was also received from Ken Chlad of Ohio Magnetics, who proposed an array of circular magnets each of diameter 1.22 meters. Circular magnets have the advantage of a greater depth of weight. The chief disadvantage is that the circular magnet does not allow the tight packing density of rectangular magnets. This could be circumvented, however, by a two line staggered array of five magnets.

Since the suggested stock magnets have manganese steel bottom plates, they thus may already have the needed resistance to UXO explosions. Testing of this hypothesis should, however, be carried out by Land Forces. The magnets each have a mass of approximately 1090 kg for a total mass of 5450 kg for five magnets, which could easily be lifted by the 30000 kg Sherman Tank. Engineering design of the supporting system will have to be carried out by Land Forces, but Ohio Magnetics has expressed some willingness to assist and has suggested that a horizontal bar and short chain-type suspension would be feasible. Furthermore, although Ohio Magnetics does not sell strain gauges or load cells for the load detection system, various crane and scale companies do and Ohio Magnetics will do the R&D required to interface such a system. Power requirements could probably be satisfied with a tank mounted 20 kw generator. Cost of such a system is difficult to estimate but can be broken down very roughly as follows:

5 magnets x $6K per magnet	$30K
1 Generator and Control Electronics	6K
Design and Misc. Hardware	4K
	$40K

It must be emphasized that, prior to the existence of firm contract demand, such figures, particularly for design, are very crude estimates. Delivery time for the magnets would be prompt.

Recommendations

1) Contract demands should be issued as soon as possible for the implementation of the noncontinuous sweep system. Although delivery time for the magnets will be prompt, support designs and tank modifications which must be undertaken will necessitate immediate action if the system is to be on line by summer 1979.

2) MSD personnel at Picatinny Arsenal have recently modified an APC as a tow vehicle for two items of commercial road building and construction equipment. This vehicle, which is equipped with television cameras and air conditioning, is being used to study the feasibility of mechanical

UXO surface clearance. It would be beneficial for military personnel to study the modifications as they might pertain to the proposed magnet system.

3) Travel funds for contract inspection and liaison should be obtained in addition to contract funds.

4) It is believed that a continuous pickup and dumping system is worth pursuing. As such, a more detailed look at such a system, possibly through a contract demand, should be initiated forthwith. Final design and construction should, however, await delivery of the short term system. Long term solutions are discussed in Appendix 2 and sources mentioned there have expressed willingness to undertake R&D on such long term systems.

5) Further information concerning short and long term systems will be forwarded as it becomes available.

6) Upon delivery of the short term system, its abilities to pick up partially buried UXO and shrapnel should be determined by extensive testing.

APPENDIX 1

Partial List of Sources

1. Reyrolle Parsons of Canada Ltd.
   610 8th Avenue S.W. Suite 705
   Calgary, Alberta
   T2P 1G5
   Telephone: (403) 262-7726
   Telex: 03-821819
   Attn: Mr. David Banks
   Manager
   Western Region
   (Parent Company: Hi-Flux Magnetics, U.K.)

2. Canrep Ltd.
   a) 5817 103 St.
      Edmonton, Alberta
      T6H 2H3
      Attn: Mr. Dave Dykmann
      Telephone: (403) 263-0225

   b) 400 330 9th Ave. S.W.
      Calgary, Alberta
      Attn: Mr. Charlie Woodward
      Telephone: (403) 262-4507
   (Parent Company: Ohio Magnetics
   5398 Denham Road
   Maple Heights 44137
   Ohio, U.S.A.
   Telephone: (216) 662-8484
   Attn: Mr. Ken Chlad)

3. Eriez of Canada Ltd.
   133 Oakdale Road
   Downsview, Ontario
   M3N 1W2
   Telephone: (416) 742-9993
   Telex: 06-965619
   (Parent Company: Eriez Magnetics
   Ashbury Road at Airport
   Erie, Pennsylvania, 16512)

4. Tormag Magnet Sales
   Vancouver, B.C.
   Telephone: Ze 08658

5. Dr. R.M. Mathur
   Dept. of Electrical Engineering
   University of Manitoba
   Winnipeg, Manitoba
   R3T 2N2

APPENDIX 2

Long Term Surface Clearance Solutions

1) Superconducting Coil Magnets

Reyrolle Parsons has suggested the alternative of using superconducting coil magnets in order to save weight. They already possess such a magnet with the following specifications:

Dimensions: 2.7 m i.d.
3.3 m o.d.
0.2 m long

Cryogenic capacity: 12 hours per liquid helium filling

Power requirement: 1 kw generator.

Additional requirement: Home based liquid helium condensing facility.

The weight of such a unit would be very light, since no iron core is necessary. The cost, however, would be in the neighbourhood of $200K. There is a possibility that the price, which is in part due to R&D costs, would decrease with time. It should be looked at as a potential replacement for the magnets of the conventional system as they wear out, if costs then warrant it.

2) Continuous Pickup and Transfer Systems

Reyrolle Parsons and Ohio Magnetics have both suggested that they already have the necessary expertise and facilities to design a continuous pickup system. Such systems would probably consist of a rotating drum modified from existing conveyor belt type units that both firms already possess. Special mounting arrangements might be needed since Ohio Magnetics suggests that such a device could have a mass of approximately 6800 kg.

Another possible source of such a system is Dr. R.M. Mathur of the University of Manitoba. A detailed proposal to be submitted in conjunction with Bristol Aerospace of Canada Ltd. is expected shortly. Further details will be forwarded.

ANNEX B

MAGNETIC SURFACE UXO SWEEPER EVALUATION

Field Program Procedure 48

1. TITLE MAGNETIC SURFACE UXO SWEEPER EVALUATION

2. BACKGROUND

It appears that there are a sufficient number of active training areas in Canada that are so contaminated with unexploded buried ordnance (UXO) as to make automated surface clearance techniques desirable. Following a request by DMEO investigations were initiated into methods which might automatically remove all ferrous metals from the ground surface. Such methods would also be of use as a preliminary step on heavily contaminated ranges prior to implementing UXO search techniques.

A variety of methods have been investigated and on the basis of preliminary tests the best appears to be a linear transverse array of existing stock magnets equipped with load cells and pushed by an armoured vehicle. Following a study by Mines Range Clearance Group DMEO has contracted for the assembly of such an array mounted in front of a Sherman Tank. The following is a detailed outline of the necessary testing procedures for such a system.

3. GENERAL DESCRIPTION

The purpose of this evaluation is to determine the conditions under which UXO can be picked up by the magnetic sweeper to be tested. A variety of parameters are expected to influence the system performance specifically:

1. Shape and size of shell
2. Shape and size distribution of shrapnel
3. Amount of shrapnel on the ground
4. Amount of shrapnel on the magnet
5. Distance from shell to magnet
6. Terrain type
7. Vegetative cover
8. Relative shell to magnet position
9. Magnet traverse speed

Ideally, one should examine the combined effect of all influencing factors but this would require an enormous number of individual tests. Thus, it is necessary to examine the influence of each of the factors while maintaining the others constant. For those factors suspected of being strongly interconnected, experiments combining the two should be performed. Furthermore, sufficient time should be allotted to allow examination of any unforeseen influences which are discovered during the planned testing.

4. TEST OBJECTIVES

4.1 Establish the feasibility of using a magnetic sweeper to clear the ground surface of UXO through determination of the maximum pick-up distance for different shell types as a function of the influencing parameters.

4.2 If feasibility is established, determine an operating procedure for most efficient use of the system.

4.3 Based on the outcome of tests related to the previous objectives, determine potential improvements or modifications which would enhance performance.

5. TEST PROCEDURE

5.1 Familiarization with Equipment

5.2 Uncluttered Shell Pickup Tests for Various Terrain Types

5.2.1 Bare Flat Terrain

i. Stationary Vehicle - Find the maximum pickup distance for the following orientations of shell lying on the ground:

a. Parallel to the vehicle direction
b. Perpendicular to the vehicle direction
c. 45^{o} to the vehicle direction

The procedure should be repeated for shell centroid positions:

a. at the center of one of the magnets
b. 50 cm outward from the center on a line perpendicular to the vehicle direction
c. 100 cm outward from the center on a line perpendicular to the vehicle direction
d. 150 cm outward from the center on a line perpendicular to the vehicle direction.

The complete procedure is to be done for 155 mm and 40 mm shells. If the trends for both types are similar, only the maximum pickup distance for the worst case need be determined for the other shell types. Otherwise, the complete procedure must be carried out for intermediate sized shells.

ii. Moving Dynamic Vehicle - Procedure 5.2.1.i should be repeated for vehicle speeds of 2, 4, 6 and 8 kph.

5.2.2 Grassy Flat Ground

The procedure for 5.2.1 should be followed except that only the shell orientations and centroid positions corresponding to the worst pickup conditions as determined in 5.2.1 need be used. Both static and dynamic tests should be done. Shells should be placed under the grass flush with the ground so as to maximize the detrimental effects of the grass.

5.2.3 Typical Uneven Bare Ground

An abbreviated dynamic test should be performed to determine the effect of uneven ground on magnet operation. The effects of magnet motions will be investigated as well as the ability to pick up shells using the optimum parameters determined in section 5.2.1.

5.2.4 Flat Ground with Scrub Brush.

The procedure for 5.2.2 should be followed.

5.3 Shell pickup Tests on Terrain Cluttered with Shells

Bare flat ground should be used throughout this portion of the testing.

5.3.1 Stationary Vehicle - Find the maximum pickup distance for the various shell types with 1,2,3.....9 shells (or as many as possible) already held on the magnet. For a single shell already on the magnet investigate the effect of shell position on the maximum pickup distance. As in 5.2.1 do the 155 mm and 40 mm shells first and others if necessary.

5.3.2 Dynamic Vehicle - Carry out procedure 5.3.1 when the vehicle passes over the shell at 2, 4, 6 and 8 kph.

5.4 Shell Pickup Tests for Terrain Cluttered Sparsely with Shells, Densely with Shrapnel

In this test it is assumed that the density of UXO is such that only one shell is picked up prior to dumping the magnet. Bare flat ground is to be used throughout.

5.4.1 Stationary Vehicle - Find the maximum pickup distance for a single shell centred on the magnet with 5, 10, 25, 50 and 100 kg of coarse shrapnel on the magnet. As in 5.2.1 and 5.3.1 perform the tests with 155 mm and 40 mm shells first and then with others if necessary. Repeat the above procedure for fine shrapnel.

5.4.2 Dynamic Vehicle - Repeat 5.4.1 for the vehicle moving at 2, 4, 6, and 8 kph.

5.4.3 Dynamic Test with Shell and Shrapnel on Ground - This test is performed to quantitatively evaluate the optimum sweep height for 155 mm and 40 mm shells. With one shell lying directly below the magnet centre, amidst 5, 10, 25 and 50 kg of coarse and fine shrapnel on the ground, perform passes at the optimum speed as determined in 5.4.2. Displace the shell 1 m to the right and repeat the procedure. If there should be a drastic difference in pickup capability, the procedure should be repeated for 50 cm displacement.

5.5 Performance on Partially Buried Shells

It is extremely difficult, if not impossible, to plan conclusive tests to evaluate the magnet's performance on partially buried shells. However, based on previous test results and time permitting, a qualitative evaluation will be carried out on some "typical" partially buried shells. It is to be noted, however, that the best evaluation of this aspect of the system's performance will be the feedback from personnel operating the system during actual clearance operations.

5.6 Dumping Mechanism and Performance on Turns

The efficiency of the dumping mechanism will be checked. Also the pickup performance of the magnets on a turn will be monitored in order to determine a suitable traversing procedure. These tests will be carried out for an optimum case based on previous tests.

6. EQUIPMENT REQUIREMENTS

1. Tank with magnets
2. Support for tank
3. Dummy shells preferably the same weight as live ones

Type	Quantity
155 mm	at least 10
105 mm	at least 10
81 mm	at least 10
60 mm	at least 10
LAW rockets	at least 10
40 mm	1 crate
20 mm	1 crate
106 mm recoilless	2

4. Shrapnel (Typical)
   a. Coarse (approximately greater than 10 cm x 15 cm) - 100 kg
   b. Fine - 100 kg

5. Weigh Scale (0 - 100 kg): Should be capable of weighing shrapnel and shells.
6. Miscellaneous Measuring Equipment - 1 stop watch, 2 tape measures, 5 meter sticks, marking stakes, 1 level, 1 plumb-line, 1 compass, to be brought by DRES.
7. Video tape recorder, camera and associated equipment such as battery pack
8. Radios to communicate with operator of the tank
9. Wheel Barrow
10. Gaussmeter (Hall effect probe) to be provided by DRES
11. Vehicles for transport of personnel and equipment
12. Calculator, portable small tape recorder, polaroid camera, writing material, to be supplied by DRES.

7. PERSONNEL REQUIREMENTS
   1. 2 Professionals from MRCG (DRES)
   2. 1 Technologist from MRCG (DRES)
   3. 1 Photographer (during the last day of trials) to take color/ b.w. photographs for reports
   4. 1 Tank Operator
   5. 1 Mechanic
   6. 3 sappers + 1 HA qualified EOD type personnel
   7. 3 drivers for vehicles

   Personnel requirements of Numbers 4 - 7 are DMEO responsibility.

8. WEATHER - No special requirements

9. SITE

The location of the trials at CFB Wainright is not crucial, although it should be preferably close to the base in order to expedite travel to and from the area and to allow minor modifications or additions to equipment to be easily made. The location should, if possible, possess all the required terrain types within a short drive of one another. The ground surface should be as free as possible of UXO. The site is to be selected by DMEO.

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13. ABSTRACT

This paper describes trials carried out at CFB Wainwright to determine the feasibility of a prototype magnetic sweeper vehicle for military range surface clearance of unexploded ordnance and shrapnel. The effects on pickup performance of terrain type, vegetative cover, shell type, vehicle speed, magnet power, position and orientation of shell relative to the magnet, and magnet-to-ground distance are all investigated. Performance is seen to be very good for most shell types and the main factor affecting performance is seen to be magnet-to-ground distance. A number of recommendations for vehicle redesign and for operational procedures are also included.

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